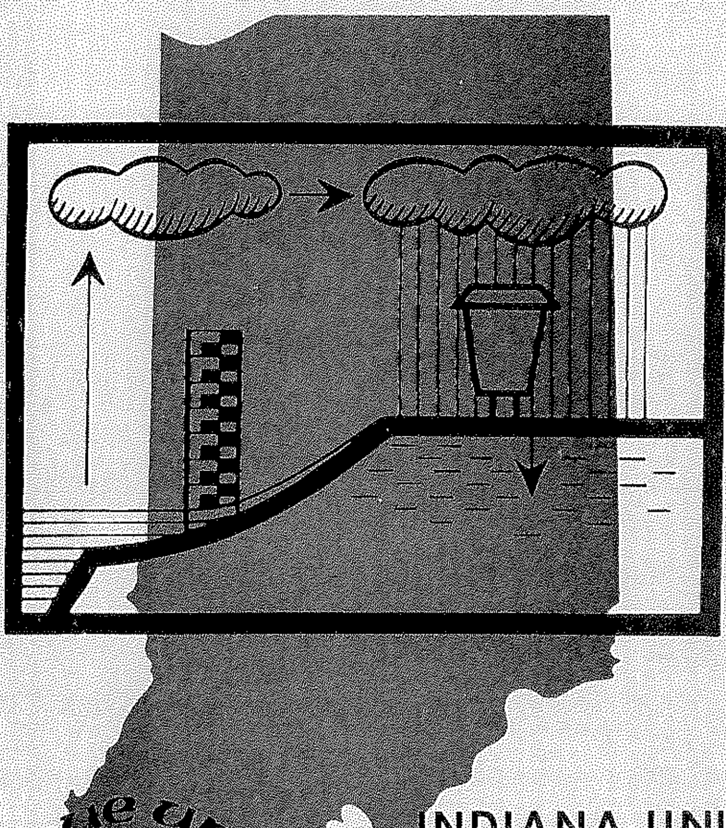
TECHNICAL REPORT NO. 66

A LAND CAPABILITY MODEL FOR THE LOWER LAKE MONROE WATERSHED



J.R. Chiesa

M.C. Roberts

J.C. Randolph

R.S. Howe

JULY 1975

INDIANA UNIVERSITY
WATER RESOURCES RESEARCH CENTER
in cooperation with
PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER

A LAND CAPABILITY MODEL FOR THE LOWER LAKE MONROE WATERSHED

by

J. R. Chiesa
M. C. Roberts
J. C. Randolph
R. S. Howe

Completion Report
Project No. A-039-IND
OWRT Title I Allotment Agreement No. 14-31-0001-5014
December 1, 1974 - June 30, 1975

The work upon which this publication is based was supported in part by funds provided by the United States Department of Interior Office of Water Research and Technology, as authorized by the Water Resources Act of 1964 (PL 88-379) as amended.

Indiana University Water Resources Research Center
in cooperation with
Purdue University Water Resources Research Center

July 1975

TABLE OF CONTENTS

INTRODUCTON

The purpose of this study is to develop a preliminary land-use capability model for a 100 square mile area surrounding Lake Monroe, a 10,750-acre reservoir in south central Indiana. This study can be viewed as an extension of the Lake Monroe Land Suitability Study (1975) which provides land-use, geological, and ecological inventories for the Lake Monroe area. A second goal of the present study is to develop a user-oriented interactive computer program which will make both the inventory and the model output available to planners, prospective developers, and other interested citizens.

Capability analysis is the synthetic, quantitative evaluation of the limitations which physical land variables may impose on the potential of a parcel of land for a variety of human uses. Capability analysis is most useful early in the planning process, e.g., examining potential sites for a proposed project. The physical variables considered in a capability analysis can be combined with social variables to produce a suitability analysis which can be used as a basis for regional planning. The present model is not a suitability model and thus does not consider social variables.

The Lake Monroe study describes the area's geology, terrestrial and aquatic ecology, current land use, and the institutional framework determining political and legal jurisdiction over the area. In the Lake Monroe study, the significance of the various types of data with reference to land-use considerations is discussed. A geologic description of the area is given, and the soil-material characteristics of each of the area's geologic subdivisions are outlined; these are then related to such land-use factors as on-site septic disposal, foundation and excavation conditions, slope stability, and ground water. The Lake Monroe area forests and wildlife and their management are considered; the influence of forests in regulating runoff and erosion are discussed. The study describes the physical and chemical properties of the lake itself and the potential damage which might result from increased phosphate input. Current land uses of the surrounding area are mapped and questions of land development, zoning, and land-use change are considered. Finally, federal, state, and local agencies having powers bearing on the planning and development of the Lake Monroe region are listed and their roles described.

LAKE MONROE INVENTORY

Most of the geological, ecological, and land-use information collected during the Lake Monroe Land Suitability Study is processed by a computerized data management program utilizing magnetic tape. These data are organized using a 10-acre-cell grid system. The 10-acre cell provides a rational method of subdividing the 640-acre section. Without further modification the cell system could be extended to the entire county, as well as being further subdivided. This grid system is seen in Figure 1. Inventory data for any one of the 6003 cells of the study area may be obtained by activating the computer program and entering the cell co-ordinates (x,y).

Many of these data were taken from the four maps (topography, geology, vegetation, and land-use) compiled for the Lake Monroe Land Suitability Study. The topography map follows the USGS 1:24,000 quadrangle series and serves as a base map. Cell relief, elevation, slope, and aspect data were derived from this map.

The geologic map indicates the distribution of six distinct geologic areas. The geologic map was compiled first by a field study in which many outcrops of bedrock and soil materials were observed, briefly described, and located on USGS 1:24,000 topographic maps. Then the study area was viewed on several sets of aerial photographs; the information derived from analysis of the aerial photographs was transferred to the base map. The soil materials overlying bedrock were sampled at 31 sites in the study area. Most of these sites were investigated by soil coring and augering using a truck-mounted drill. Information derived from these studies was then integrated into the geologic map. The geologic mapping units are: (1) limestone with < 20% slopes, (2) limestone with > 20% slopes, (3) siltstone with < 20% slopes, (4) siltstone with > 20% slopes, (5) terrace and colluvium, and (6) alluvium. Geologic mapping unit, soil thickness, sinkhole, and drillhole data were taken from this map.

A generalized vegetation map was developed using USGS 1:24,000 topographic maps, USDA 1:20,000 aerial photographs, and field surveys. This map gives the extent and location of (1) early "old field" successional vegetation, (2) young successional or disturbed forest, and (3) mature forests. A detailed forest species composition analysis was based on this map and on 35 field transects in which emphasis was placed upon selective sampling of forests within the study area. The forest composition data from the transects were grouped into various slope, aspect, elevation, and geological mapping unit categories. The elevation and aspect categories resulted in the most distinct vegetational gradients, an analysis of which resulted in the delineation of 36 different forest compositions. The forest composition for any given cell is inferred from a cross analysis of elevation and aspect for that cell. Forest distribution and projected composition are included in the inventory.

For the land-use maps, all cells accessible by automobile were mapped in the field. Each cell was located on a USGS 1:24,000 topographic map. Each 10-acre cell was divided into ninths, resulting in approximately 1.1-acre quadrats. The information for each cell was collected on a form designed as a map, on which the land-use boundaries and the land-use code were indicated. For those cells not mapped directly, the data were assembled using aerial photographs. When the mapping was completed, ancillary data such as zoning classifications were collected. Current land-use types, relative locations, predominant zoning, and current settlement were derived from this source.

An example of the inventory for cell 25-53 is given in Table 1. Each cell is identified by cell co-ordinates, township and range co-ordinates, section number, and township name.

Table 1: Example of Cell Inventory Data

Cell (25,53)	T8N R1W	Perry Township	Section 36

A. Current Land Use Types
   9 Ninths of the cell are being used for private forests

B. Cell Relief (Feet) 80

C. Relative Location

Aerial distance to nearest shoreline (Miles)	1.0
Road distance to nearest launching ramp (Miles)	1.0
Road distance from cell to nearest access road (Miles)	0.6
Road distance to Bloomington (Courthouse) (Miles)	10

   Cell is not located on a peninsula
   Cell is within watershed boundary

D. Predominant Zoning Of Cell Residential

E. Current Settlement

Number of residences in the cell	0
Number of trailers in the cell	0
Number of other buildings in the cell	0

F. Geological Mapping Units
   The cell is
   6 Ninths siltstone, > 20 per cent slope
   3 Ninths alluvium (Mostly silt)

G. Soil Thickness: Unknown

H. There Are Neither Sinkholes Nor Drillholes In The Cell

I. The Modal Slope of the Cell is 23 Per Cent

J. The Following Aspects Are Present In The Cell
   North-facing slope
   South-facing slope
   Bottomland
   Ridge top

K. Minimum Elevation Within The Cell: 620 Feet
   Maximum Elevation Within The Cell: 712 Feet

Table 1: continued

L. Expected Forest Composition:

American Beech	14.4 Per Cent
Shellbark Hickory	5.2 Per Cent
White Oak	14.7 Per Cent
Red Oak	12.5 Per Cent
Sugar Maple	15.1 Per Cent
Black Oak	5.9 Per Cent
Tulip Tree	5.0 Per Cent
Others	27.3 Per Cent

(Percentages are Importance Values)

CAPABILITY ANALYSIS

Previous Approaches

Although land capability analysis is a new adjunct to city planning it is not a new concept. It has been extensively used in agricultural land-use planning, for the agronomist has long recognized the need to evaluate the agricultural potential of land based on the inherent physical capability of land. Jacks, in what is now a dated (1946), but nevertheless valuable, monograph on land classification, gives an agriculturist's view of the value of capability techniques. He takes a definite stand on the need for agricultural capability/land classification studies to put an emphasis on the incorporation of conservation practices. What is clear from Jack's review is the variety and scope of the agricultural approaches to capability analysis.

The most widely used system of land capability analysis is that developed by the U.S. Department of Agriculture based on the results of soil surveys (Hedge and Klingebiel, 1957; Kellogg, 1935). By using soil type, slope, and erosion conditions, the U.S.D.A. has set up a classification with eight capability classes.

In the state of Ohio recognition of the value of land capability analysis has reached a stage where it is used as an ongoing part of the program of the Ohio Department of Natural Resources (ODNR), Division of Planning. In a recent publication (ODNR, 1973) the philosophy of the Ohio approach was put in the following way:

"Land capability planning treats the physical environment as a dynamic entity that cannot be used in disregard to the processes and inter-relationships of nature and man. Man is included as a factor of nature, and his developmental proposals for land usage are studied in light of possible impact on a disruption of nature.

Capability planning effectively deals with the difference in the physical environment from place to place across the landscape. Differences in major landscape features are obvious, however, a close examination will indicate many more subtle differences or variations, such as soil differences, flooding potential, vegetation, elevation, wildlife, etc." (p.5-6)

The applications of this philosophical position can be found in the various publications of the ODNR (DiGennaro, Secor, and Leeson, 1974; Dunn and Marshall, 1974; Marshall and LaValle, 1974; Ohio Department of Natural Resources, 1974; Tyson and LaValle, 1974) produced for various administrative units in the state of Ohio.

A somewhat different and more broadly ranging approach is that taken by Fabos and his colleagues dealing with the impact of urbanization (of the Boston area) on the natural environment (Fabos et. al., 1973). Their research is not concerned directly with land capability analysis but their use of landscape resource assessment is a multivariate accounting of the human use of the environment.

Lyle and von Wodtke (1974) describe the derivation of a "best-action model," which is essentially a capability concept, from an environmental information system.

The body of literature just reviewed provides in varying ways the conceptual base of this study. In practical terms the work of the ODNR is the most valuable because it was developed to meet a similar need--the evaluation of the physical environment for planning in a Midwestern milieu.

Land-Use Categories

The land-use categories relevant to the Lake Monroe area are:

- Residential
- Agriculture
- Commercial
- Recreation

These land uses are the ones most prevalent in the area today and are, therefore, the uses which the capability model should address. One task of the model is to incorporate the differing capability demands of the four land uses. This is accomplished by weighting the variables differently for each land use.

Residential land uses (single-family and multi-family units) can be built on a wide range of slopes if cost is of little importance. However, most developments have economic constraints, and slope is a critical physical restriction (because of the extra grading required, the great difficulty of installing and using septic tanks, soil erosion problems, and landslipping). In some areas low slopes (0-2%) are a constraint on development because low slopes combined with clay soils will lead to severe drainage problems. This is not the case in the Lake Monroe area because the areas of low slope are so restricted that drainage problems can be solved by drainage ditches or tiles. Higher slopes pose an erosion problem in that any development on slope of 4% or more should include stringent sediment control measures.

The distinction between commercial and residential is not a clear-cut one because the criteria for both are not, in this area, fundamentally different. However, the following points should be considered:

a. Commercial sites should avoid hazardous areas such as floodplains and areas of potential landslip.

b. Sites should be relatively large and flat.

In socio-economic terms, additional items should be incorporated, such as:

a. Sites should be adjacent to existing commercial land-uses whenever possible.

b. Sites should be close to public utilities.

Since the present model is in the first stage of development, commercial and residential land uses have the same criteria. Once the soil survey data becomes available it will be possible to differentiate these two categories.

Agriculture, though a declining industry in the Lake Monroe area, is still practiced in the most advantageous sites such as the floodplains and the flat-land on the ridge tops. These locations, in fact, are guidelines to the criteria used for assessing agricultural capability, for although the range of slopes for agriculture is wider than for residential land uses high slopes must still be avoided. This is because row cropping on high slopes will lead to severe soil erosion. Further, the agricultural production of this area does not justify further expensive conservation measures.

Recreation land uses are an intrinsic part of the landscape around the lake and the model makes a direct recognition of this fact.

Environmental Variables

The land-use suitability model takes three environmental variables into consideration: floodplain, slope, and mature forest. The value each variable can take is divided into several coded categories, starting with a code of one for those values which render the cell most suitable for development. Those categories of values with increasing codes are progressively less suitable for development. The codes go up to six or ten, depending on the value. A code of ten represents those variable values which indicate that the cell is incapable for development. The same coded category set holds for each variable over all land-use options. Differences in the relevance of a particular variable to the various land-use options are accounted for by a system of weights described in the next section. A description of the environmental variables and their associated coded categories of values follows.

Presence of floodplains. This variable takes on values ranging from zero to nine ninths, depending on the fraction of the cell covered by floodplain. While there is no direct mention of floodplain presence in the data inventory, it is conservatively assumed that a floodplain is associated always and only with the geological mapping unit designated "alluvium." A cell containing no floodplain is given a code of one; a cell containing one to three ninths of floodplain is coded two; one containing four to six ninths is coded three; seven ninths is coded four, and eight ninths five; a cell which is totally floodplain is coded ten --

totally incapable of development. A progressive scale is used here to indicate that the greater the fraction of the cell covered by floodplain, the greater is the probability that a development planned for a portion of that cell is on undevelopable land, or, for those sites which occupy a full cell, the greater is the fraction of the site that is undevelopable. A code of ten serves as a warning that the whole cell is undevelopable.

Slope. The values for the modal slope of a cell range from zero per cent to over forty per cent, and are coded as follows. A slope of zero to two per cent is given a code of one; a slope of three to six per cent is coded two; seven to twelve per cent is coded three; thirteen to eighteen per cent four; and nineteen to twenty-five per cent five. A cell with a modal slope greater than twenty-five per cent is coded ten, incapable of development. These slope standards are less restrictive than those used in the Ohio studies and allow for extenuating physical circumstances to mitigate the effects of unfavorable slope conditions.

Presence of Mature Forest. The amount of a cell covered by mature forest can range from zero to nine ninths. The coded category set is the same as that used for presence of floodplains, except that a cell completely covered (nine ninths) by mature forest is coded six instead of ten. The presence of mature forest does not incapacitate a cell for development, but can make it highly undesirable. A progressive scale is used because the greater the fraction of mature forest in the cell, the more forest may have to be destroyed by the development, and the less desirable it is to develop the cell.

All three of the environmental variables used in this study are also used in the Ohio capability analyses. Indeed, these are very similar to three of the four variables used in DiGennaro, Secor, and Leeson (1974), the only one missing being soils, due to the lack of a complete soil survey of the area. The Ohio studies refer to the first two environmental variables listed above under the heading of "on-site problems." However, they also point out that resource-loss problems should be taken into consideration in determining the capability of land for development. Certainly one of the most important, if not the most important, terrestrial resource in the Lake Monroe area is the mature forest which helps make the area so attractive for development in the first place.

Weighting System

Because a given environmental variable can affect different land uses differently, each of the three coded environmental variable values are multiplied by a weight before being averaged to derive a capability rating. The weight values range from 0.1 to one, and depend on the land use under consideration. A weight of 0.1 indicates that the environmental variable has no effect on the land use under consideration, regardless of the variable's value. A weight of one indicates a very important effect. In this preliminary model, only weights of 0.1, 0.5, and 1.0 have been given. While these values are arbitrary and do not allow fine differences to be made between the effects of different variables on land use, they are sufficient to elicit the important differences which are the aim of this initial mode. A description of the system of weights assigned to each environmental variable follows.

Presence of Floodplains. As this variable is an important consideration in site selection for residential and commercial development, a weight of one is assigned for those purposes. Floodplains may also be important considerations in some types of residential development, but may have little or no effect on other types. A weight of 0.5 is thus assigned to residential development. Floodplains have little or no deleterious effect on agriculture, and a weight of 0.1 is attached in this case.

Slope. Slope is a serious consideration for any residential or commercial development, and a weight of one is thus attached. Again, its effect on recreational development depends on the type of recreational development planned, so slope is weighted 0.5 for that purpose, and also for agriculture, where slope is of some importance, though not as much as for residential or commercial development.

Presence of Mature Forest. The conversion of forested land to residential or commercial development or to agriculture requires the destruction of forest, and a weight of one is assigned. Since recreational development can sometimes be undertaken in harmony with a natural environment (and sometimes not), a weight of 0.5 is attached to that option.

Results

For each land use in a given cell, an average capability rating is calculated. This rating is the average of the products of the three codes (floodplains, slope, and mature forest) and their associated weights. A table of weighted codes and average capability ratings for each of the four land-use categories constitutes the land capability evaluation section of the computer output for a given cell.

Table 2 presents the land capability evaluation for cell 25-53, the inventory data for which is given in Table 1. The average capability ratings are fairly high, i.e., the cell is relatively incapable of development, due to its relatively steep slope and to its being fully covered by mature forest. The compatibility of some types of recreational development with forest preservation and the reduced significance of slope for some types of recreational development result in the cell's being evaluated as fairly capable for recreational use. The difference between the residential/commercial and agricultural ratings is due to the irrelevance of floodplains with respect to agriculture, as opposed to their importance for residential or commercial development. This is reflected in the first row of Table 1, where the low weight for the floodplain code under "agriculture" results in a low weighted code and finally in a low average capability rating.

As a further example of the manner in which the model output can be used, the data inventory and land capability evaluation for a 240-cell portion of the study area have been summarized in Table 3 and in Figure 1. The land capability maps in Figure 1 are a graphic presentation of the relative capability of the cells in that area for residential or commercial development and for agricultural development. This is shown by grouping capability ratings into capability classes. The maps show how the relatively steep slopes in the area (see Table 3) render many of the cells incapable of development. Maps such as these could be an important aid to planners and developers.

Table 2: Land Capability Evaluation for Cell 25-53.

Cell Feature	Capability Rating for: Residential Development	Commercial Development	Agricultural Development	Recreational Development
Presence of Floodplains	2.0	2.0	0.2	1.0
Slope	5.0	5.0	5.0	2.5
Presence of Mature Forest	6.0	6.0	6.0	3.0
Average Capability Ratings	4.3	4.3	3.7	2.2

The lower the rating, the more capable is the cell for the use under consideration.

Table 3: Summary of Selected Inventory Data for Cells 25-34 to 36-53.

Current Land Use Types

	Acres	Percent of Area
Total area	2400	100.0
Residential	123	5.1
Commercial	19	0.8
Agricultural	167	7.0
Recreation	163	6.8
Forest	1332	55.5
Water	596	24.8

Cell Relief

Greatest relief (185 feet) occurs in cell 36-13

Zoning Classification

	Number of Cells	Percent of Total
Residential	152	77.6
Commercial	1	0.5
Agricultural	0	0
Recreation	0	0
Forest	43	21.9
Other	0	0

Current Settlement

Total number of residences	26
Total number of trailers	4

Geological Mapping Units	Number of acres	Percent of area
Limestone, slopes < 20%	169	10.4
Limestone, slopes > 20%	7	0.4
Siltstone, slopes < 20%	191	11.8
Siltstone, slopes > 20%	1089	67.0
Terrace and colluvium	86	4.9
Alluvium	91	5.6

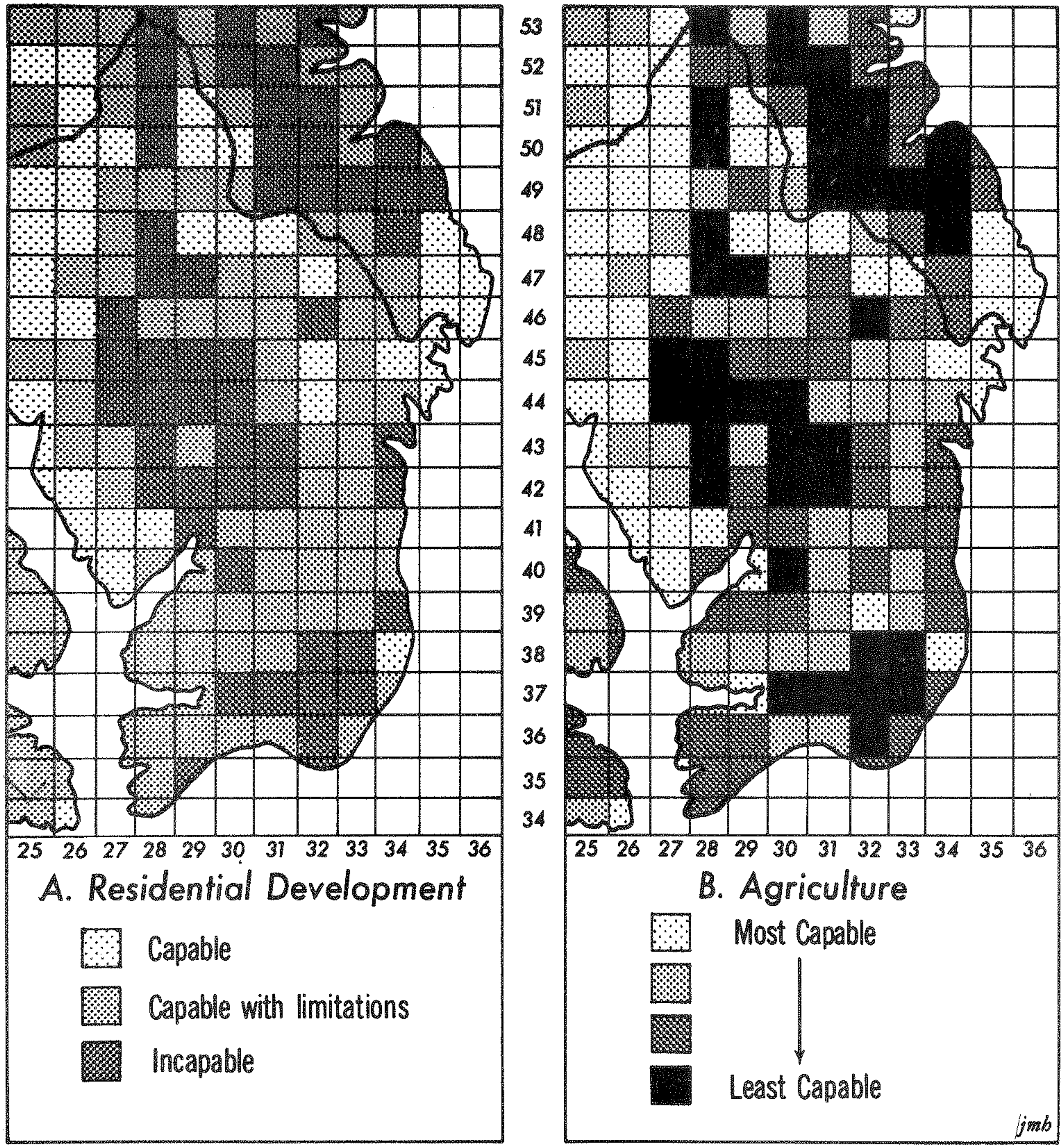
Slope

	Number of cells	Percent of total
Slopes > 25%	102	42.5

Elevation

Minimum	550 feet
Maximum	760 feet

Figure 1. Land Capability Evaluation



FUTURE DIRECTIONS

The analytical approach used in developing the present model is of significant utility to the planning process. In any situation in which environmental-economic tradeoffs must be evaluated, in which an optimum balance between environmental and economic values must be achieved, in which resource losses must be weighted against economic growth only a quantitative analysis of physical and social data can unravel the complex interactions involved. The Lake Monroe land capability model represents only a start towards such an analysis. The model can only be utilized as a preliminary screening process to eliminate from consideration those sites which involve building on floodplains or on steep slopes or in mature forests. Even for a physical capability analysis, more than this needs to be taken into consideration. However, even a full capability analysis is not sufficient grounds on which to formulate a regional plan. Expansion to a suitability analysis by the inclusion of socio-economic variables is required.

The one important physical variable used in the Ohio Department of Natural Resources capability analyses but not in this model is soil. This variable had to be omitted from the Lake Monroe model due to the lack of a complete, modern soil survey for Monroe County. Such a survey is now in progress, but will not be finished for several years. Just the same, it may soon be practicable to incorporate what soil data that does exist into the model.

In its role as an environmental variable, the soil is actually a complex of variables (see Table 4). Certain of these variables relate to the soil's ability to support structures while not corroding them, while others are more relevant to agricultural considerations. These soil variables are essential for a complete capability analysis.

When a complete capability analysis has been achieved, the model can still be made of even greater utility to planners and developers if it is expanded to a suitability analysis by the addition of socioeconomic variables. Some of the variables already present in the land-use section of the data inventory which might be used in a suitability analysis include road distances from the cell to various resources such as Bloomington and the lake, the present zoning of the cell, and the current land use of the cell, the latter being of particular importance, of course. Important variables to be included in a sophisticated model would be the current land uses in adjacent cells and the area and location of land already used in a manner similar to that in the proposed development. Such a sophisticated model could help greatly in the formulation of a regional plan, but the development of such a model would of course entail the commitment of resources not presently available.

Table 4. Soil variables to be used in future land capability analyses.

Soil-specific Variables

Erosion Potential
Flooding
Drainage Class
Depth to Seasonal Water Table
Potential Frost Action
Depth to Bedrock
Stoniness
Rockiness

Horizon-dependent Variables

Horizon Depth
Shrink-swell Potential
Unified Classification
Corrosion Potential--Steel
Corrosion Potential--Concrete
Permeability Rate

Bibliography

DiGennaro, Alfred A., Edwin S. Secor, and David E. Leeson. 1974. Conotton Creek Subwatershed Analysis. Ohio Department of Natural Resources, Columbus, Ohio. 116 pp.

Dunn, Thomas J. Jr., and David C. Marshall. 1974. Land Capability Analysis, County Report No. 1, Lake County. Ohio Department of Natural Resources, Columbus, Ohio. 55 pp.

Fabos, J.G., R. Careaga, A.S. Wilson. 1973. Model for Landscape Resource Assessment, Part I of the "Metropolitan Landscape Planning Model" (METLAND): University of Massachusetts, Agric. Expt. Sta., Research Bull., No. 602, 141 pp.

Hedge, A.M., and A.A. Klingebiel. 1957. The use of soil maps. In Soil: The Yearbook of Agriculture. The United States Department of Agriculture. The United States Government Printing Office, Washington, D.C. pp. 400-411.

Jacks, R.V. 1946. Land Classification for Land-Use Planning. Technical Communication No. 43, Imperial Bureau of Soil Science, Harpenden, England.

Kellogg, C.E. 1935. A system of land classification. In Transactions of the Third International Congress on Soil Science. Vol 1. pp 283-286.

Lyle, John and Mark von Wodtke. 1974. An information system for environmental planning. AIP Journal: 394-413.

Marshall, David C., and David C. LaValle. 1974. Big Darby Creek Corridor Study. Ohio Department of Natural Resources, Columbus, Ohio. 109 pp.

Ohio Department of Natural Resources. 1973. A New Approach to Land-Use Planning. Ohio Department of Natural Resources, Columbus, Ohio. 22 pp.

__________. 1974. Land Capability Analysis: The Wolf Creek Pilot Project. Ohio Department of Natural Resources, Columbus, Ohio. 55 pp.

School of Public and Environmental Affairs. 1975. Lake Monroe Land Suitability Study: A Technical Report On A Selected Portion of The Lake Monroe Watershed. Indiana University, Bloomington, Indiana. 446 pp.

Tyson, Thomas T., and David C. LaValle. 1974. Madison County Planning Resource Study. Ohio Department of Natural Resources, Columbus, Ohio. 60 pp.